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AUTHOR Miller, Gary G.
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INSTITUTION Air Force Human Resources Lab., Lowry AFB, Colo. Technical Training Div.
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ABSTRACT

A two-phase effort was conducted to design and evaluate a maintenance simulator which incorporated state-of-the-art information in simulation and instructional technology. The particular equipment selected to be simulated was the 6883 Convert/Flight Controls Test Station. Phase I included a generalized block diagram of the computer-trainer, the functions involved, and an evaluation design yet to be finalized. Phase II dealt with the data concerning the training capabilities and potential of the 6883 simulator. Imagetics, an evaluation technique, was investigated for use. (Imagetics was defined as a method of developing and testing the degree of a student's ability to develop and retain a mental image by causing the student to record responses indicative of the image development in a manner such that the responses are not immediately visible to the student.) Moreover, plans were made during the evaluation to develop and validate a set of Imagetics materials against an actual job sample and to assess the effectiveness of using imagery as a training technique. This two-phase effort resulted in future plans to use the 6883 as a research vehicle to determine where, when, and how much simulation is necessary in Air Force training for the maintenance and operation of certain test equipment. (Also included in this report are an introductory discussion covering definitions of simulation systems, reasons for using simulation, the relationship between the training equipment and psychology, and the status of simulation.) (VB)

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New Directions in Maintenance Simulation

Gary G. Miller

Technical Training Division

Air Force Human Resources Laboratory

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Running head: Maintenance Simulation

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Abstract

The objective of this study was to exploit the state-of-the-art in simulation technology via the design, development and fabrication of a simulator for training Air Force technicians to perform complex, "hands-on" maintenance tasks. Although simulation technology has been successfully applied to the training of most aircrew tasks, relatively little application of this technology has been made in the training of complex maintenance tasks. This paper reviews the state-of-the-art in maintenance simulation technology, discusses the enormous training and cost benefits of simulation, and describes the design and evaluation of a maintenance simulator which incorporates state-of-the-art simulation and instructional technology.

New Directions in Maintenance Simulation

Over the past several years there has been a renewed interest in the military in the development of simulation technology for maintenance training. Fink, Shriver, Downing, and Miller (1978) observed that, although simulation in maintenance training is often viewed as a new concept, research in this area began in earnest after World War II. Since the early 1950s the U.S. Air Force has sponsored the development of maintenance simulators, especially those which could be used to teach the troubleshooting of electronic equipment. Despite numerous studies which demonstrated their cost effectiveness, the use of simulators for maintenance training still is not widespread and there is considerable resistance to such usage. As the result of recent advances in simulation technology, and the need to conserve training dollars, the Air Force is making a concerted effort to develop information about maintenance simulators and to demonstrate their applicability. This report provides some background on simulation in the Air Force, a description of the results of a current project, and concludes with an identification of some areas where future research is required.

Simulation Systems

Definitions

Definitions of simulation and simulators abound; see Miller (1974)

for a review. Nonetheless, certain general features characterize nearly all simulator-based training systems.

First, these systems incorporate devices that duplicate, in varying degree the appearance and operation of selected actual equipment. The resultant "stimulators" range in complexity from simplistic cardboard mock-ups to the very sophisticated flight simulators used in pilot training. The essential feature is that the simulators provide "sufficient" realism 1) to evoke and permit practice of specified job-related tasks, and 2) to enhance transfer of the learned skills/knowledge to real-world job environments. Certain aspects of the actual equipment are deliberately omitted; that is, the simulators are characterized by less than 100% engineering fidelity. The simulators become cost-effective training devices when these omissions are based on careful identifications of how the devices are to be used in the training environment - what persons with what entry-level skills/knowledge are to be trained to perform what set of tasks to what level of proficiency under what conditions?

Secondly, simulator-based training systems may incorporate supporting instructional features - trainer-unique features and capabilities not inherent to the actual equipment. These features

could include carefully controlled learning situations, step-by-step monitoring of trainee actions, performance feedback, automated instruction, and well designed student and/or instructor station consoles. Again, however, the requirement for these various adjunct features must be based on a clear specification of intended simulator trainer use.

Reasons for Using Simulation

Fink, et al (1978) have noted that countless research studies, field tests and application reports have demonstrated that, for a variety of training situations, simulators are more cost effective than Actual Equipment Trainers (AET). These findings are fully accepted with respect to pilot training (Montemerlo, 1977); it is now unthinkable to develop a new aircraft without also developing flight simulators for pilot training. In fact, many airlines believe that in the 1980s it will be possible to conduct total pilot training in the flight simulator (Gustafson, et al, 1957). Although there have been some pioneering efforts geared towards using simulators for training maintenance personnel, there still appears to be some resistance to their employment.

Miller (1974) has stated the prevailing view of training technologists that simulators offer significant cost, reliability and

training-effectiveness advantages over the use of actual equipment trainers. Research and application studies also have shown that low-cost training equipments and training aids can be cost-effective substitutes for actual equipment trainers or expensive simulators. As Fink, et al (1978) observed, a simulator is another piece of equipment, and one should not be surprised by the finding that it too can be replaced, on occasion, by less expensive training devices.

Training Equipment and Psychology

Although professionals of many disciplines are often involved in the design and fabrication of training equipment, many are surprised to learn that training psychologists play an important role in simulator design and development. When little or no attention is paid to the psychological factors of training equipment design, the resulting training equipment often ends up being a complete engineering duplicate of operational equipment. The "full engineering" approach has thus been criticized as producing trainers that are too expensive and too realistic. It has long been known that in the initial stages of training that too much realism can overwhelm the trainee. What is more often needed is some abstraction of the job situation that is specifically tailored to the learning environment. Psychologists can make unique contributions in the process of translating training device requirements into training equipment designs by looking for opportunities to optimize the relationship between cost, fidelity, and transfer

of training, as discussed by Miller, 1953. The disciplines of job/task analysis, learning theory, instructional technology, and experimental design are all critical to effective design, evaluation, and research in training equipment.

To paraphrase Gagne (1967), it is not the sophistication of the training device that has accounted for some of the remarkable successes in troubleshooting training. Instead, most of the success can be attributed to the identification and analysis of the tasks, sub-tasks, and components of a job. The analysis of the task structure and proper sequencing of tasks are what can be considered to be the first and primary tasks of the training device designer. As was aptly stated by Muckler, Nygard, O'Kelly and Williams (1959), "costs could be considerably reduced if researchers would concentrate their efforts on improving the manner in which training devices are used rather than relying on the exact replication of actual equipment for effective training." Gagne (1954) also pointed out that the task being simulated should not be the equipment itself. If that were the case, then every simulator would be an exact representation of the operational equipment.

Although many advances have been made (since the early fifties) in the design and utilization of simulators for maintenance training, it is interesting to note that far fewer advances have been made in the

psychological foundations of training equipment design. Many of the terms familiar to us now, such as stages of learning, transfer of training, cost-effectiveness, and fidelity were first discussed with reference to training equipment during that period. Renewed research in simulation has opened up many of the above issues that are, for the most part, still unresolved.

Chief among these unresolved issues is fidelity. What is, or how does one determine, the appropriate level of physical/operational realism to ensure effective training? Miller (1953) and Gagne (1954) have both emphasized the distinction between engineering and psychological fidelity. Full engineering fidelity requires that the physical and functiona characteristics of actual operational equipment be duplicated within very tight tolerance specifications - whether or not those characteristics provide critical cues or required interfaces for the trainee learning a particular job. Maximum psychological fidelity, on the other hand, requires only that degree of equipment duplication necessary for the trainee to transfer to the job environment (with zero decrement) those responses he learns to perform in the training environment. After reviewing the major studies in maintenance simulation, Miller (1974) concluded that engineering fidelity can be quite low in devices used to train certain procedural tasks without degrading transfer of training. Other issues

such as the training-effectiveness of maintenance simulators, cost-effectiveness, and user acceptance are yet to be resolved; however, the pace of simulator implementation in the military has moved ahead of research and development. According to Fink, et al (1978) this situation has caused researchers to react to hardware developments rather than identifying the directions these developments should take.

Status of Simulation

Although most of the applications of simulation have utilized two-dimensional panel approaches, other approaches such as three-dimensional, computer graphics and simple paper and pencil approaches are well within the current state-of-the-art. Not surprisingly, the cost of the products produced by these four approaches varies inversely with the physical fidelity of the simulation produced by each approach. But, aside from certain equipment characteristics or maintenance tasks which are still difficult to simulate, it does appear that the state-of-the-art in simulation technology has advanced to where maintenance simulators can be used to produce a performance capability in course graduates which is not achievable with traditional actual equipment trainers. Unfortunately, the need for or usefulness of this increased performance capability is not always acknowledged by instructors and some segments of the training system or training

program acquisition system. This seems to be because the training system seldom has been expected to produce personnel with a practical troubleshooting capability at graduation, from a basic course. Historically, major changes in capability seldom come about through a perceived need. Rather, an improved technology creates a need for more of the technology. As the cost-effectiveness of simulators becomes more widely known, there probably will be increased agitation for producing course graduates who have an increased capability to troubleshoot equipment. (Fink, et al, 1978)

Problem

Most of the systematic compilations of rules and principles governing the cost-effective use of simulation were developed during the early 1950s. Although there have been applications of simulation in technical training over the past several years, only a few of the studies have attempted to use a cost-effective approach based upon previously developed rules and principles. In general, the methodologies that have been developed for the application of simulation have been long and cumbersome. Attempts at validating rules and principles have been relatively rare, and, as a result, little more is known now about the application of simulation in technical training than was known 20 years ago. We have arrived at a point today where most of the "how to do it" hardware problems in

simulation have been overcome. The time has come to concentrate on where and when simulation technology can best be applied and under what conditions. In addition to determining when and where simulation can be effective, a need exists to determine how much simulation (fidelity) is required for the simulation of various maintenance tasks. The level of reality duplicated in a simulator obviously has enormous costs and training implications. The above problems are being addressed in an Air Force Human Resources Laboratory project that I would like to discuss next.

6883 Simulator Development

Approach

A two phased effort is currently underway at AFHRL to design, fabricate, and evaluate a state-of-the-art maintenance simulator for learning complex maintenance tasks.

The particular equipment selected to be simulated was the 6883 Converter/Flight Controls Test Station designed to maintain five Line Replaceable Units (LRUs) from the F-111D. It was chosen because: 1) it is representative of complex, automatic, electronic test stations found in I-level maintenance shops; 2) it suffers from extremely low availability, particularly in the classroom; and 3) the tasks required

to operate and maintain the 6883 are largely procedural and thereby readily adaptable to a computer-driven/monitored training system.

Phase I - Simulator Development

Generalized Block Diagram. The 6883 Maintenance Trainer is a multi-computer system which drives simulations of the 6883 Test Station and associated LRUs through appropriate interface hardware. Student actions on the simulated equipment are sensed by the computer through the same interfaces. Appropriate student guidance and feedback is provided by a CRT/keyboard and random access slide projector. Student performance is recorded by the computer system and is output to the instructor's CRT/keyboard in summarized form. These same performance data are output to a cassette tape and high-speed printer for record keeping. Figure 1 illustrates the training system hardware block diagram.

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Insert Figure 1 about here

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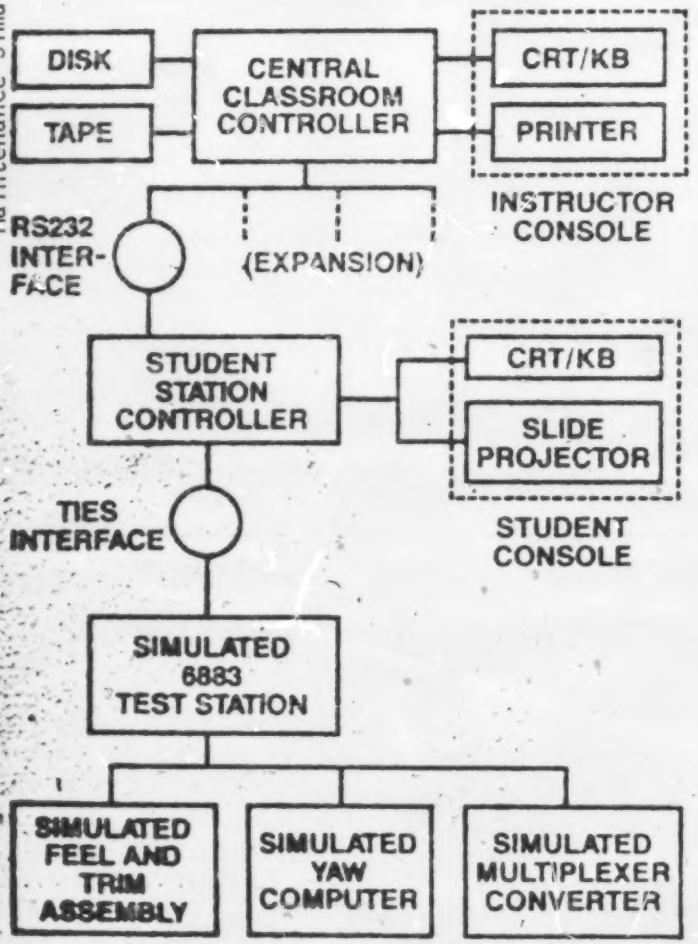
The 6883 Maintenance Training Simulator is controlled by two Honeywell Information Systems Model 716 computers (hereafter referred to as H716's). The computer system architecture is a multi-processor, distributed system providing expansion capabilities. One H716 computer functions as a classroom controller, operating the instructor

6883 SYSTEM ELEMENTS
HARDWARE/SOFTWARE BLOCK DIAGRAM

HARDWARE



BASIC SYSTEM SOFTWARE

- EXECUTIVE
- SUBSYSTEMS
- I/O COMPONENTS
- UTILITIES
- DIAGNOSTICS

TRAINER COMMON MODULES

- TRAINING SYSTEM CONTROLLER
- STUDENT PROCEDURE
- INSTRUCTOR MONITOR
- STUDENT TEST
- TRAINER SELF-TEST
- O-SCOPE SIMULATION
- DVM SIMULATION

6883 SPECIFIC MODULES

- INSTRUCTION PROCEDURE
- SLIDE ADDRESS FILES
- TEXT MESSAGES
- TEST STATION SIMULATION FILE
- LRU SIMULATION FILES

Figure 1. 6883 Maintenance Training System Block Diagram

station CRT/keyboard, high-speed printer, disk, tape drives, and interprocessor interface. In addition, the classroom controller performs the following functions:

- o store program segments on the disk;
- o satisfy program loading requests of the 6883 Simulator LRUs and
- o act as a software development device for programming the station controller while the system is not being used for instruction.

Data transfer between the classroom controller and the student station controller is performed using an industry standard RS232 interface. Three (or more) additional RS232 interfaces may be used to connect additional test station simulators to the classroom controller. The 6883 simulator computer architecture is therefore designed to permit low-cost, rapid expansion to a total of four or more simulated test stations. In this manner, a single instructor at his console can simultaneously monitor several different station simulators.

The second H716 functions as the student station controller. The student station controller operates the student CRT/keyboard, random access display unit, interprocessor interface, I/O multiplexer and test station and LRU simulation features. A Trainer Interface

Electronics System (TIES) provides an input/output multiplexing capability for sensing student actions and for driving displays and indicators in the simulated equipment. A random access Mast slide projector is computer-controlled through this multiplexer. The student station controller is designed to provide the following functions:

- o operate all digital/analog conversion hardware;
- o process all student actions at both the CRT/keyboard and the test station/LRU simulation;
- o request additional program data segments from the classroom controller;
- o drive all students CAI;
- o transmit student performance data to the classroom controller for display to the instructor; and
- o cooperate with the system controller to perform simulator self-diagnostic procedures.

Generalized Trainer Layout. The 6883 Maintenance Training System installation layout has been designed to provide optimal efficiency and ease of operation. An artist's conceptualization of the proposed system hardware arrangement is shown in Figure 2.

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Insert Figure 2 about here
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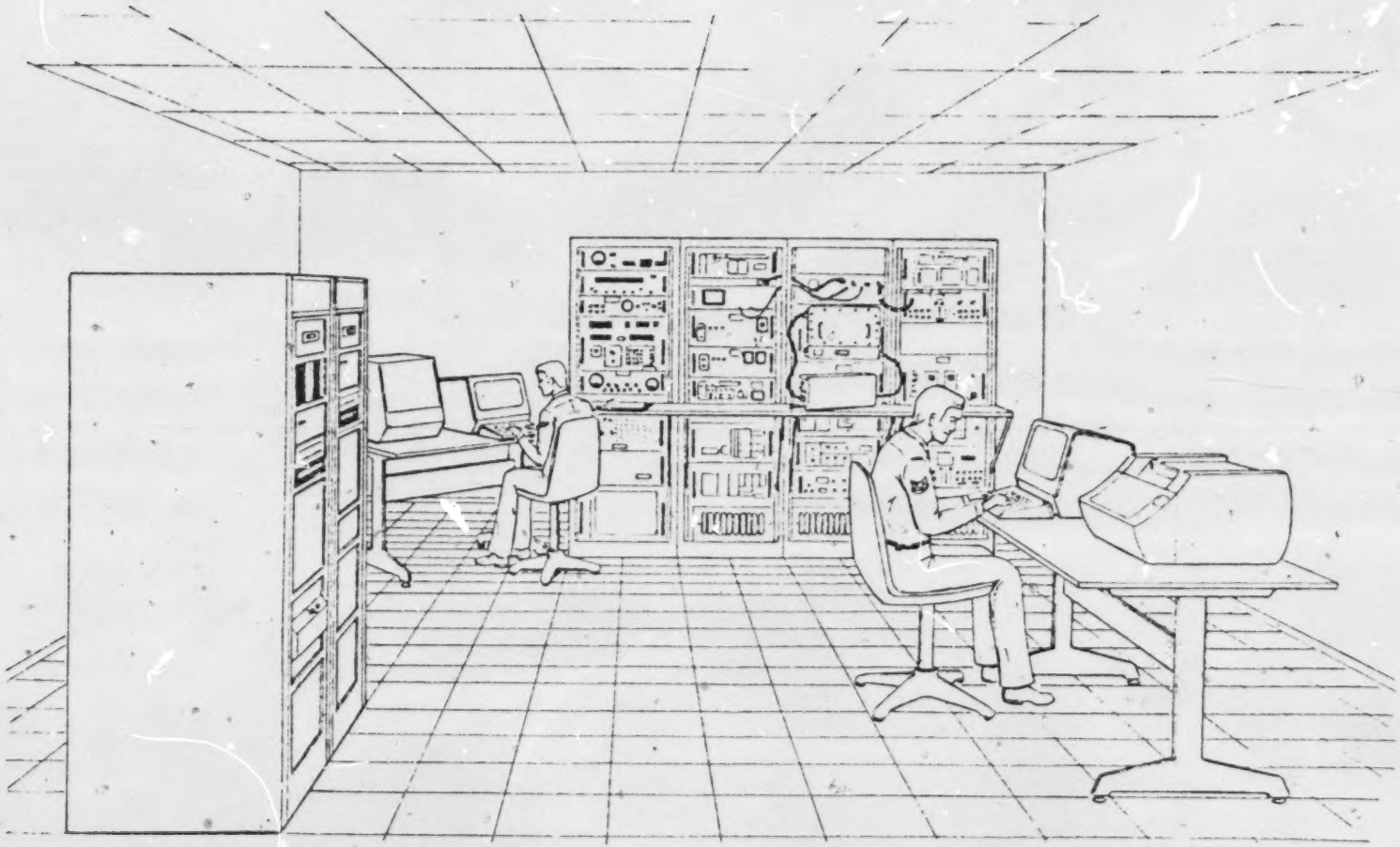

Figure 2. Artists Conceptualization of Classroom Arrangement of

The instructor console, consisting of the Instructor CRT/keyboard and highspeed line printer, is located in the right front quadrant of the room. This arrangement affords the instructor an unobstructed line-of-sight to the student console and 6883 Simulator. Easy access to the classroom and student station controllers is possible with this arrangement, thus facilitating disc changes, tape changes, and H716 front panel entries. Location of the instructor console in close proximity to the computer systems reduces the required cable lengths and probability of electromagnetic interference. A Hewlett Packard 2640B CRT keyboard is included at both the instructor and student consoles and the high-speed line printer is placed at the instructor station.

The student console, consisting of a CRT/keyboard and slide projector is located in the rear left quadrant of the room adjacent to the 6883 Simulator. Most student actions at the student console will take place at the CRT/keyboard while most actions on the 6883 Simulator will involve the DATAC panel in the far left equipment bay. The proposed room layout positions the student CRT/keyboard and DATAC panel in close proximity to simplify trainer operation. The proposed arrangement permits cabling to the student console along with the left wall, thus reducing cable lengths and possible electromagnetic interfaces.

Phase II - Evaluation

During Phase II, a comprehensive evaluation will be conducted of the training effectiveness of the 6883 simulator. Although the evaluation design has yet to be firmed up, considerable attention is being given to addressing some of the inadequacies of typical trainer evaluations. New simulators have been typically evaluated by comparing students trained on them with persons trained in the classroom or on real equipment. Montemerlo (1977), Spangenberg (1974) and others have severely criticized this research paradigm, pointing out that this type of research does not increase our understanding of the conditions for which simulators best can be employed. Furthermore, research comparing simulators with actual equipment trainers has implied that simulators can be substituted for actual equipment trainers in toto. There is no evidence that this is possible. (Fink, et al, 1978).

In general, studies on the effectiveness of maintenance simulators have compared persons trained to troubleshoot on a simulator with persons who have not been trained to troubleshoot but who perhaps have talked their way through a few troubleshooting exercises in the classroom. With rare exceptions, the "new trainer" always wins.

In order to make comparisons between the 6883 simulator and the actual equipment more meaningful, emphasis will be placed on the collection of data that emphasizes the training capabilities and potential of the 6883 simulator.

Performance Evaluation Using Imagery

One problem that has continually surfaced in simulator vs actual equipment evaluations has been the lack of an inexpensive, yet effective, criterion measure of training effectiveness. A potentially powerful technique that can be applied to the independent criterion problem is now under investigation by AFHRL. This technique is referred to as Imagetics. The Imagetics technique is defined as a method of developing and testing the degree of a student's ability to develop and retain a mental image by causing the student to record responses indicative of such image development in a manner such that the responses are not immediately visible to the student. The method provides appropriate means for recording a visible image in a location not visible to the student. A stylus, or similar instrument, is moved over a depiction of the object to be acted upon without leaving a visible trace. The recording of a mental image related to previously learned physical objects and relationships while precluding the student from directly viewing the progress or development of what he is recording improves the quality of the final recording as an indication of the complete mental picture which the student has developed. See Figure 3 for a description of the Imagetics technique.

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Insert Figure 3 about here

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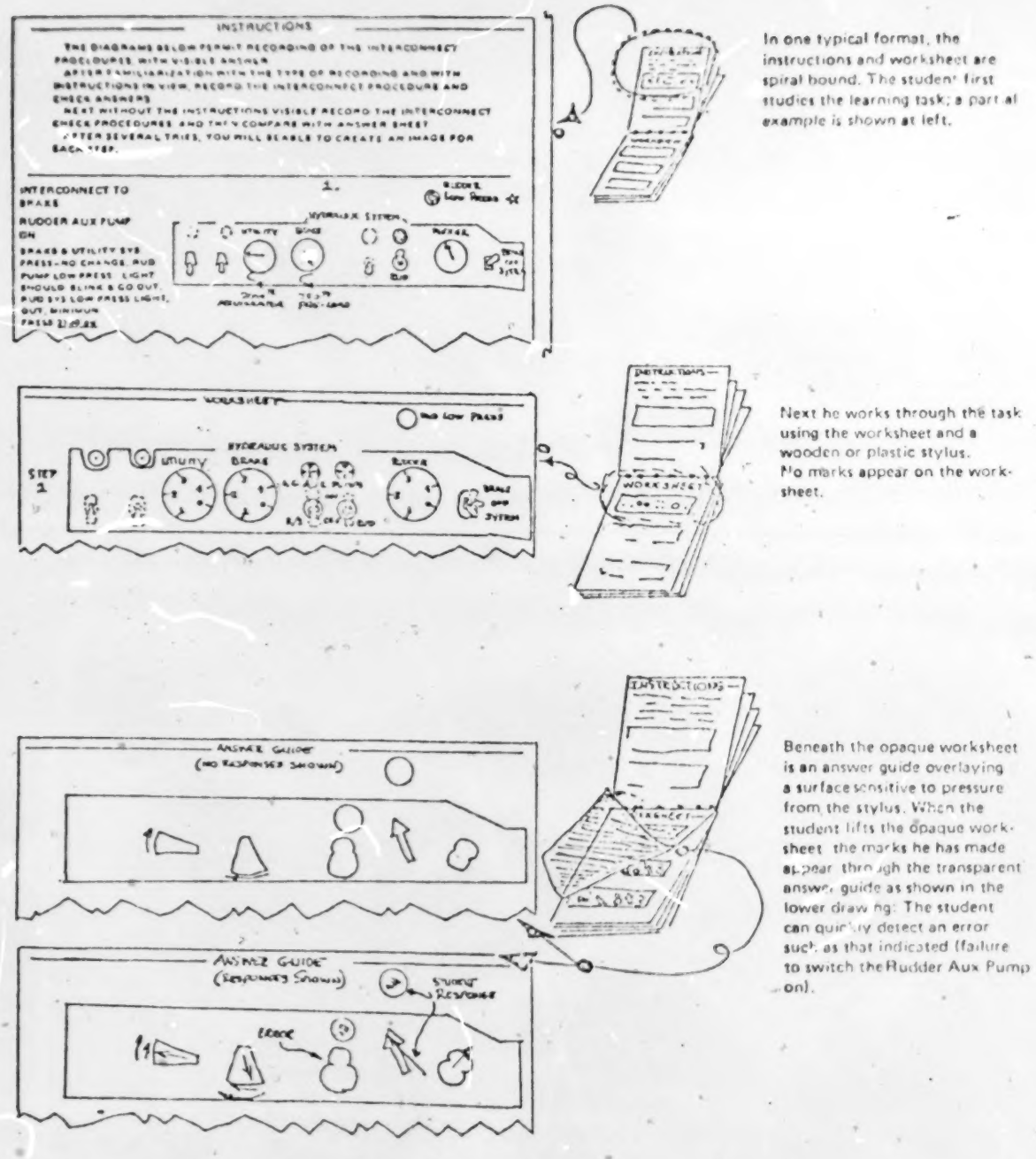
INSTRUCTIONS
THE DIAGRAMS BELOW PERMIT RECORDING OF THE INTERCONNECT PROCEDURES WITH VISIBLE ANSWER
AFTER FAMILIARIZATION WITH THE TYPE OF RECORDING AND WITH INSTRUCTIONS IN VIEW, RECORD THE INTERCONNECT PROCEDURE AND CHECK ANSWERS
NEXT WITHOUT THE INSTRUCTIONS VISIBLE RECORD THE INTERCONNECT CHECK PROCEDURES AND THEN COMPARE WITH ANSWER SHEET
AFTER SEVERAL TRIES, YOU WILL BE ABLE TO CREATE AN IMAGE FOR EACH STEP.
INTERCONNECT TO BRAKE
RUDDER AUX PUMP ON
BRAKE & UTILITY SYS PRESS - NO CHANGE, RUD PUMP LOW PRESS LIGHT SHOULD BLINK & GO OUT. RUD SYS LOW PRESS LIGHT, OUT, MINIMUM
1.
HYDRAULIC SYSTEM
UTILITY
BRAKE
RUDDER
WORKSHEET
NO LOW PRESS
HYDRAULIC SYSTEM
UTILITY
BRAKE
RUDDER
STEP 1
WORKSHEET
ANSWER GUIDE
(NO RESPONSES SHOWN)
INSTRUCTIONS
ANSWER GUIDE
(RESPONSES SHOWN)
STUDENT RESPONSE
ERASE

In one typical format, the instructions and worksheet are spiral bound. The student first studies the learning task; a part of example is shown at left.

Next he works through the task using the worksheet and a wooden or plastic stylus. No marks appear on the worksheet.

Beneath the opaque worksheet is an answer guide overlaying a surface sensitive to pressure from the stylus. When the student lifts the opaque worksheet the marks he has made appear through the transparent answer guide as shown in the lower drawing. The student can quickly detect an error such as that indicated (failure to switch the Rudder Aux Pump on).

Figure 3. Part of a learning task sequence using the Imagetics technique.

During the evaluation of the 6883 simulator, a set of Imagetics materials will be developed and validated against an actual job sample. Following the validation, the Imagetics materials will be used as a criterion measure for comparisons of training effectiveness between competing training approaches. The effectiveness of using imagery as a training technique will also be assessed.

Future Research

6883 Simulator

The 6883 described in this paper will be used primarily as a research vehicle to determine where, when, and how much simulation is necessary in AF technical training for the maintenance and operation of certain test equipment. Baseline data will be established with the 6883 simulator such that comparisons can be made with 2 dimensional, graphics, and paper and pencil techniques. By experimentally varying the level of fidelity of competing approaches to 6883 training, we hope to fill in some of the blanks in the "how much simulation is required" problem.

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